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# Hydrologic Evidence of Climate Change in Monroe County, New York

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Prepared in cooperation with the Monroe County Department of Health

# Hydrologic Evidence of Climate Change in Monroe County, New York

**I**ncreasing evidence of climate change has raised concerns that the predicted increases in air temperature and attendant changes in precipitation patterns will affect water resources around the world. An analysis of long-term meteorological and streamflow records can be used to identify trends that might be indicative of climate change, especially with respect to the magnitude and frequency of floods and droughts in western New York, including Monroe County.



Streams under drought (above) and flood (below) conditions.



## IN BRIEF . . .

- ✓ Long-term annual mean air temperatures have been increasing over the past 40 years, but not beyond the historical range as defined by temperatures that have been recorded since 1890.
- ✓ Annual precipitation totals in the Great Lakes Basin within the United States have increased by an average of 4.5 inches since 1915.
- ✓ The chance that daily precipitation will exceed 2.0 inches has increased from once in 5 years prior to 1963 to nearly once every year since 1992, and the chance that daily precipitation will exceed 2.5 inches has increased from once every 20 years to almost once every 4 years.
- ✓ In urban streams, 7-day high flows and the frequency of peak flows are increasing, whereas base flows are decreasing.
- ✓ In rural streams, base flows and 7-day low flows are increasing, whereas 7-day high flows show no discernible trend.
- ✓ Discrepancies in flow characteristics between rural and urban streams are attributed to differences in the amounts of impervious areas in each basin type.
- ✓ Flow characteristics of the Genesee River are unique because regulation of the outflow from Mount Morris Lake moderates the extreme flows, both high and low, that might otherwise occur in this river.

# Value of Long-Term Weather and Streamflow Records

The National Weather Service (NWS) has collected meteorological data in the Rochester, N.Y., area since at least 1872 (National Oceanic and Atmospheric Administration, 2007). The NWS station is currently at the Greater Rochester International Airport (fig. 1), and the data are available at the U.S. Historical Climatology Network (HCN) web site (Williams and others, 2007). This data set includes monthly average maximum, minimum, and mean air temperatures and total

monthly precipitation at more than 1,200 sites throughout the contiguous United States. Stations are selected for inclusion in this network on the basis of length of record, completeness of record, number of station relocations, and other station changes that could affect the homogeneity of the data. The records are subjected to quality-control tests and are adjusted for biases or anomalies resulting from “suspect” and “outlier” values (those that exceed 3.5 and 5.0 standard deviations from the mean, respectively); they also are adjusted for time-of-observation differences, changes in and relocation of measurement instrumentation, station relocations, and the localized warming effects caused by urbanization (Williams and others, 2007).

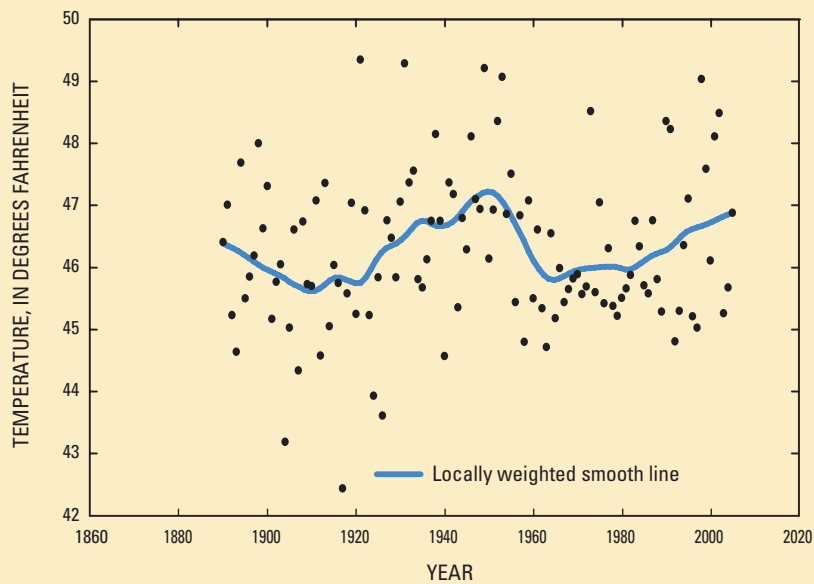


**Figure 1.** Locations of streamflow-monitoring sites and streams in Monroe County, N.Y. (Site-identification number, drainage area, and period of record for each site are given in table 1.)

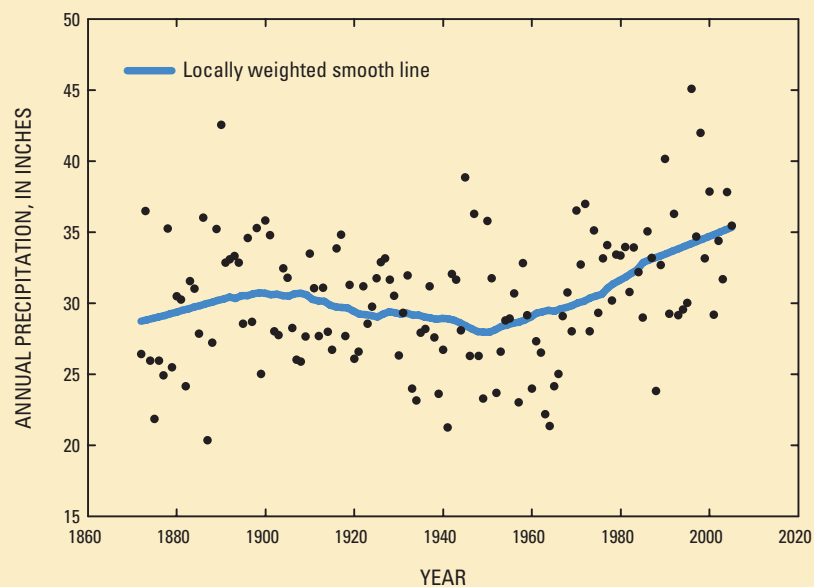
Annual mean air temperatures in Monroe County have fluctuated as much as 8 degrees Fahrenheit from 1890 through 2005, according to data from Williams and others (2007). The apparent increase in temperature over the past 4 decades is within the historical range of temperatures shown in figure 2.

Unlike the air-temperature records, the records of annual precipitation at Rochester from 1872 through 2005 (Williams and others, 2007) indicate an upward trend since about 1950 that currently exceeds historic levels (fig. 3). This trend has been verified through an analysis of annual mean precipitation records collected at 34 HCN stations across the Great Lakes Basin within the United States, including western New York, from 1915 through 2004 that indicates a 4.5-inch increase in annual precipitation during that 90-year period (Hodgkins and others, 2007).

Rainfall quantity or intensity during individual storms may be a more informative indicator of changes in precipitation patterns, and the effects of such changes, than total annual precipitation. Short-term extreme events are the most likely to produce large, potentially destructive flows. A comparison of the upward trend in annual precipitation from 1948 through 1963 with that from 1992 through 2007 indicates that (1) the average number of days per year on which precipitation exceeded 0.5 inch has increased from 16 to 22; (2) the chance that daily precipitation will exceed 2.0 inches has increased from once in 5 years to nearly once every year; and (3) the occurrence of daily precipitation in excess of 2.5 inches has increased from once every 20 years to about once every 4 years. These apparent increases in the frequency of large precipitation quantities could contribute to larger peak stormflows than have occurred in the past.



**Figure 2.** Annual mean of monthly mean air temperatures at the National Weather Service meteorological station, Rochester, N.Y., 1890–2005. (Based on data from Williams and others, 2007) (The locally weighted smooth line in figure 2 and the similar scatterplots that follow highlight the central tendency of the data.)



**Figure 3.** Annual precipitation measured at the National Weather Service meteorological station, Rochester, N.Y., 1872–2005. (Based on data from Williams and others, 2007)

# Possible Effects of an Increase in Precipitation

The possible effects of the apparent recent increase in precipitation on the water resources of the county have not been defined. The U.S. Geological Survey, in cooperation with the Monroe County Department of Health, however, has monitored streamflow and water quality in many streams in Monroe County for several decades. Six of these streams—Honeoye, Oatka, Black, Allen, and Irondequoit Creeks, and Genesee River (fig. 1; table 1)—have been monitored for periods ranging from 26 years (Irondequoit Creek) to more than 75 years (Genesee River).

Long-term streamflow records can reveal changes and trends that cannot be identified in records that cover shorter periods of time. Streamflow characteristics that can best be defined from long-term records are the magnitude and frequency of peak flows, the percentage of total streamflow that represents base flow (the ground-water component of streamflow), and the duration of low and high flows (the percentage of time that flow in a stream is likely to equal or exceed some specified value). Trends in these characteristics for the six streams and their relation to climate change in Monroe County are discussed below.

## Magnitude and Frequency of Peak Flows

Flooding in Monroe County is not new, but whether the magnitudes of peak flows are increasing, or whether floods are occurring more frequently than in the past, can be determined through an examination of peak-flow records. Because not all apparent increases in the magnitude and frequency of peak flows can be attributed to climate change, these records must

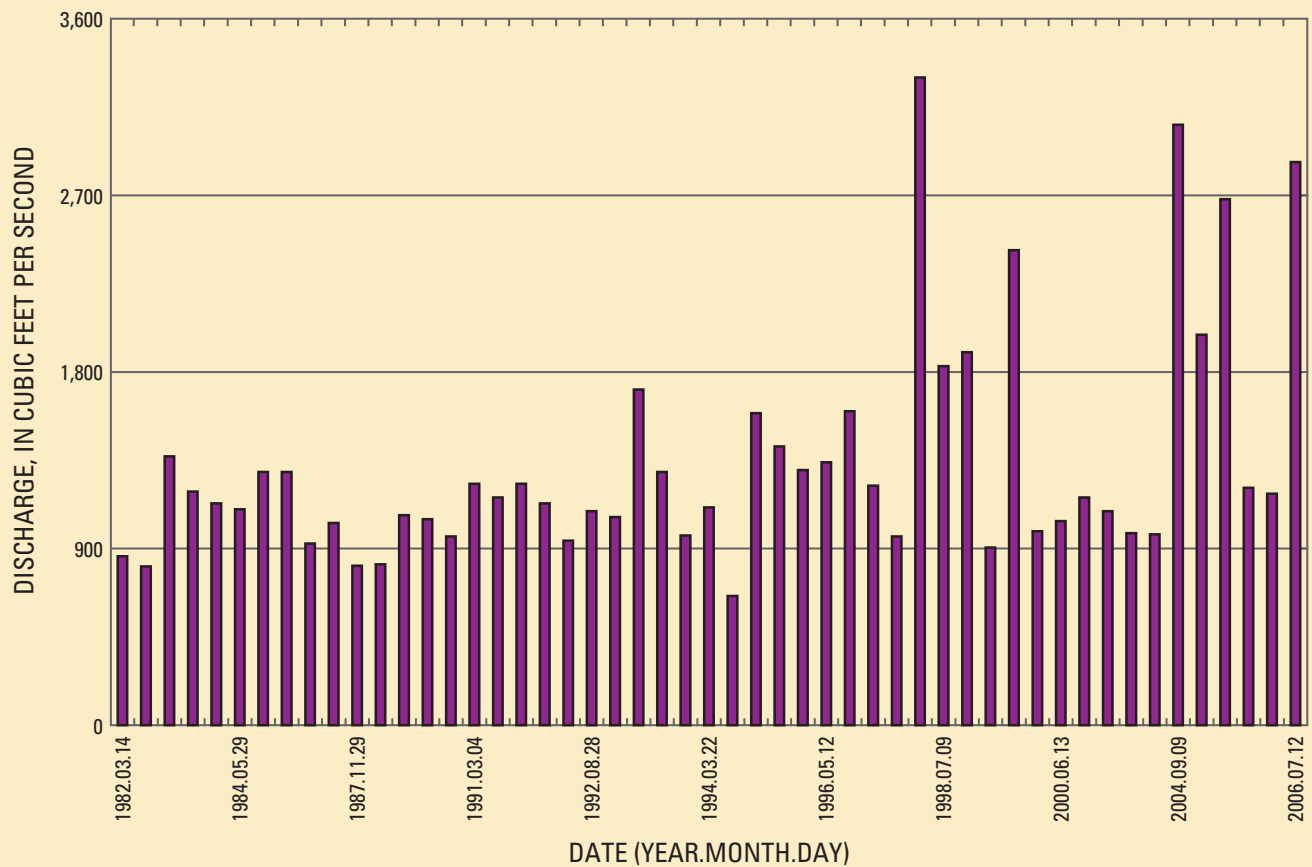
be scrutinized to identify anomalies and their causes. For example, urbanization of a watershed can affect peak flows. The magnitude of peak flows and the damages associated with flooding typically are greatest in urbanized areas, especially where floodplains have been developed. Regulation of streamflow also can affect long-term peak-flow records. Past flooding on the lower Genesee River, such as the historic floods of 1865, 1916, and 1942, is unlikely to recur because the Mount Morris Dam, constructed on the river near Mount Morris, N.Y., in 1951, provides flood protection for downstream communities.

The floods of 1960 and 1974 on Allen Creek and numerous floods during the past decade on Allen and Irondequoit Creeks are examples of regional flood events that caused extensive damage to property in the developed areas of the county. Evidence of increased flooding can be seen in the peak-flow records of these two streams. During 1998–2006, Irondequoit Creek had eight peak flows that exceeded 1,800 ft<sup>3</sup>/s (cubic feet per second), each of which exceeded the highest flow recorded during the previous 16 years (fig. 4). Peak flows on Allen Creek, which has a smaller, more developed drainage basin than Irondequoit Creek, also seem to be occurring more frequently than in the past (fig. 5). Although the number of peak flows exceeding 900 ft<sup>3</sup>/s on Allen Creek during the last 20 years (1986–2006) is equal to the number that occurred during 1960–80 (14 peak flows), only three of those flows exceeded 1,300 ft<sup>3</sup>/s during the earlier period, whereas seven flows equaled or exceeded that rate during the later period. These apparent increases in the magnitude and frequency of floods on Irondequoit and Allen Creeks in the last 20 years can be attributed partly to the increase in impervious area (roads, parking lots, and buildings) that has accompanied development in each basin, but an increase in the frequency of storms that produce large amounts of precipitation also could be a major factor.

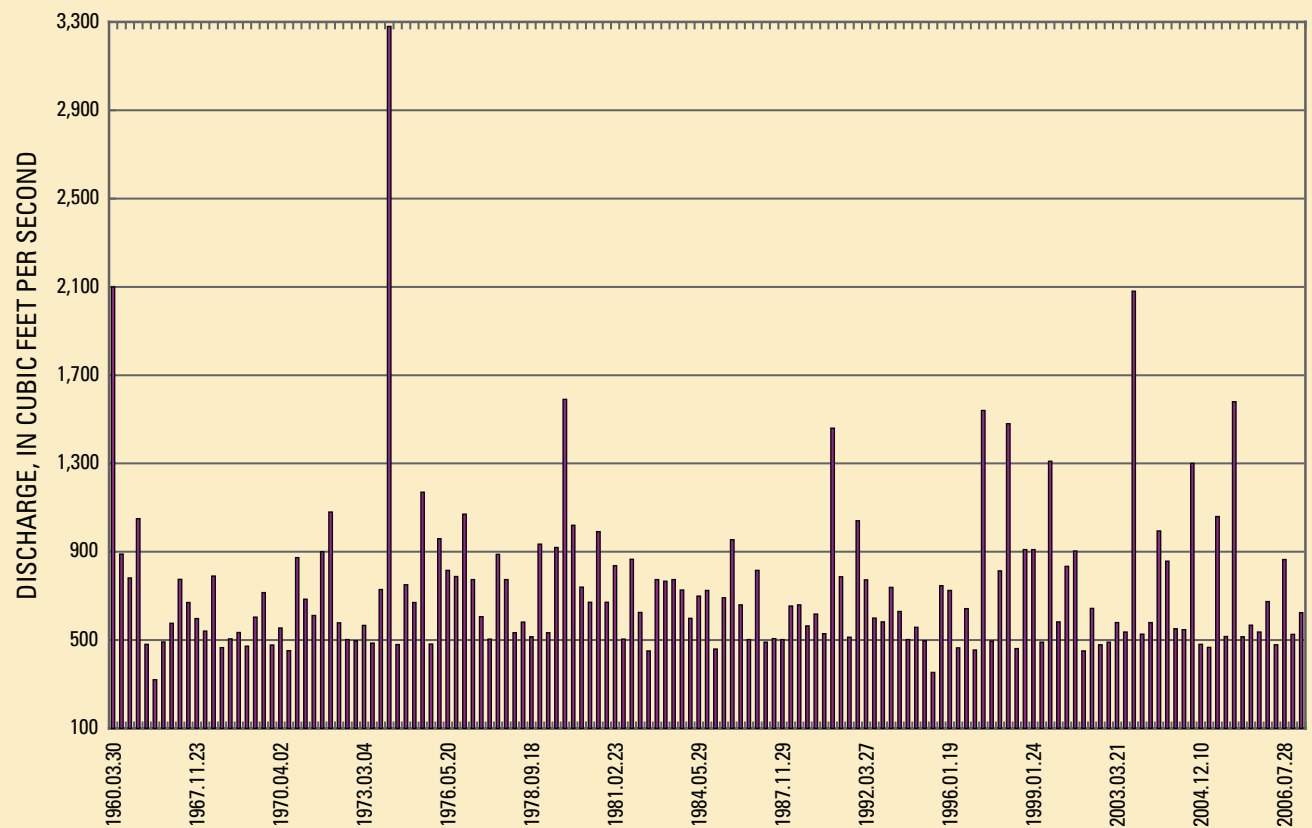
**Table 1.** Streamflow-monitoring sites in Monroe County, N.Y.

[USGS, U.S. Geological Survey; mi<sup>2</sup>, square miles. Locations are shown in fig. 1]

USGS site-identification number	Site name	Drainage area (mi <sup>2</sup> )	Period of record
04229500	Honeoye Creek at Honeoye Falls	196	1945–70; 1972–2007
04230500	Oatka Creek at Garbutt	200	1945–2007
04231000	Black Creek at Churchville	130	1945–2007
04232000	Genesee River at Rochester	2,467	1902–2007
04232050	Allen Creek near Rochester	30.1	1959–2007
0423205010	Irondequoit Creek above Blossom Road, Rochester	142	1980–2007



**Figure 4.** Annual peak flows and secondary peaks greater than 900 cubic feet per second on Irondequoit Creek above Blossom Road, Rochester, N.Y., 1982–2007.



**Figure 5.** Annual peak flows and secondary peaks greater than 450 cubic feet per second on Allen Creek near Rochester, N.Y., 1960–2007.



## Base Flow and Stormflow

Streams in the northeastern United States continue to flow even during prolonged periods of dry weather. The explanation for this phenomenon lies in the relation between surface runoff and ground water. Water in the soil and bedrock over which streams flow slowly makes its way from underground storage in pores and fractures into surface-water channels. This ground-water contribution to surface flow, which is called base flow, occurs all the time, but can be obscured by streamflow's other major component, storm runoff. As the term implies, storm runoff results from precipitation and snowmelt that flows overland or through stormwater-drainage systems into stream channels. Storm runoff creates high water levels and turbid conditions in a stream; base flow is characterized by clear water flowing in streams during long, dry periods. Computerized streamflow-separation techniques (such as the program of Sloto and Crouse, 1996) can be used to separate the base-flow component from the stormflow component in a streamflow record and provide another streamflow characteristic that can be analyzed to further assess evidence of climate change in western New York.

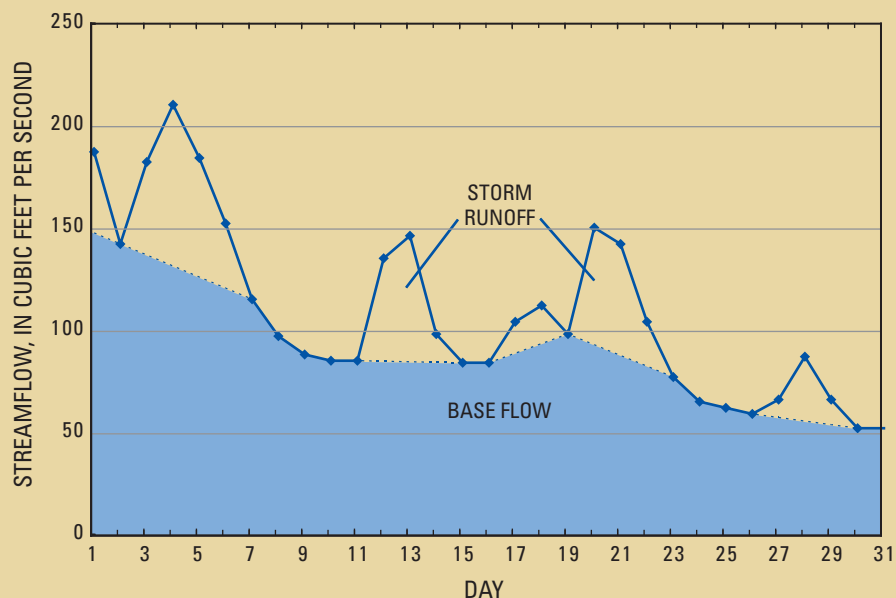
Most of the flow in streams in western New York, on an annual basis, consists of base flow despite the large volume of storm runoff that can be carried downstream during major floods. Streamflows in three rural streams in Monroe County—Oatka, Black, and Honeoye Creeks (fig. 1)—have been monitored since

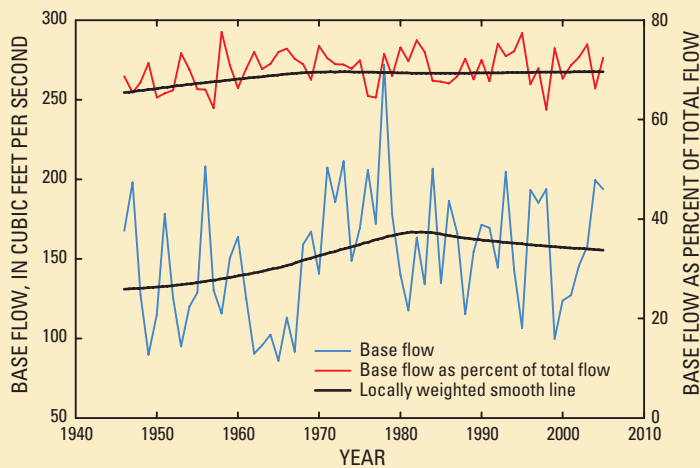
1945. The flows of Oatka and Black Creeks reflect undisturbed runoff processes, whereas those of Honeoye Creek are affected by withdrawals for water supply and regulation of outflows from Hemlock and Canadice Lakes. Nevertheless, base flow appears to have been increasing in all three creeks during their respective 60-year periods of record, although the percentage of flow that consists of base flow has remained relatively stable (figs. 6–8).

A striking difference between the 60-year trends for these three rural streams and that for Allen Creek, which drains an urbanized basin, can be seen by comparing figures 6 through 8 with figure 9. Whereas the rural streams (figs. 6–8) show an upward trend in base flows, Allen Creek (fig. 9) shows a decrease since about 1980 and a steep downward trend in base flow as a percentage of total flow—a pattern not seen in the data from the rural streams. The differences between the urban site (Allen Creek) and the rural sites are even more pronounced when the periods of record of the rural streams are shortened to coincide with that of Allen Creek (1961–2005). The downward trend in the Allen Creek base flows presumably reflects this basin's large amount of impervious area, which facilitates rapid runoff to storm sewers or nearby stream channels and inhibits infiltration of precipitation that would otherwise replenish the ground-water system. Thus, a decrease in ground-water storage due to urbanization is expressed as a decrease in base flow. A similar analysis of the Irondequoit Creek data, which cover a shorter period of record than the Allen Creek data, did not show any clear trends.

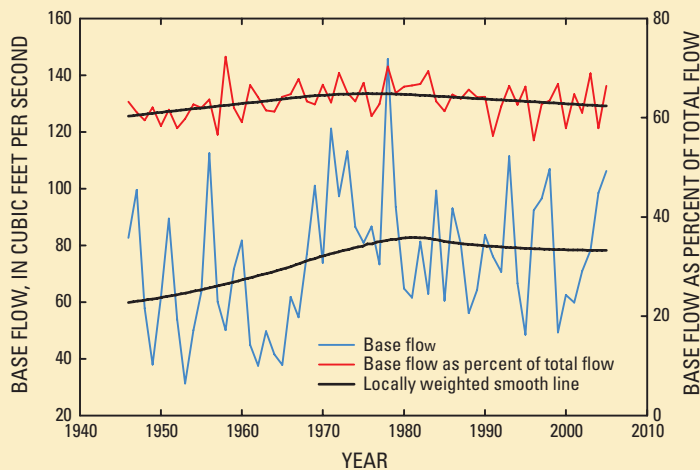
### Streamflow Separation

Streamflow can be separated into its two flow components—base flow and storm runoff—by several methods, each of which systematically draws connecting lines between the low points of the streamflow hydrograph (Sloto and Crouse, 1996). The local-minimum method, which often is used to identify these low points, can be visualized as connecting the lowest points on the hydrograph with straight lines, as illustrated (right). Base flow values for each day between the selected local minima are estimated by linear interpolation.

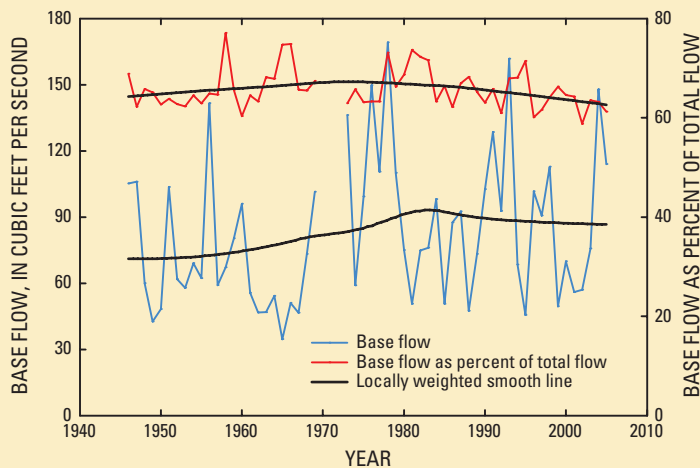




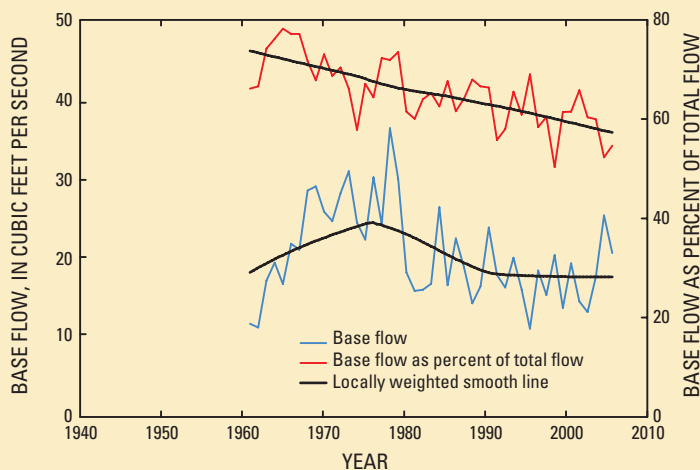
**Figure 6.** Annual mean base flow and base flow as a percentage of total flow, Oatka Creek, 1946–2005.



**Figure 7.** Annual mean base flow and base flow as a percentage of total flow, Black Creek, 1946–2005.



**Figure 8.** Annual mean base flow and base flow as a percentage of total flow, Honeoye Creek, 1946–2005.



**Figure 9.** Annual mean base flow and base flow as a percentage of total flow, Allen Creek, 1961–2005.



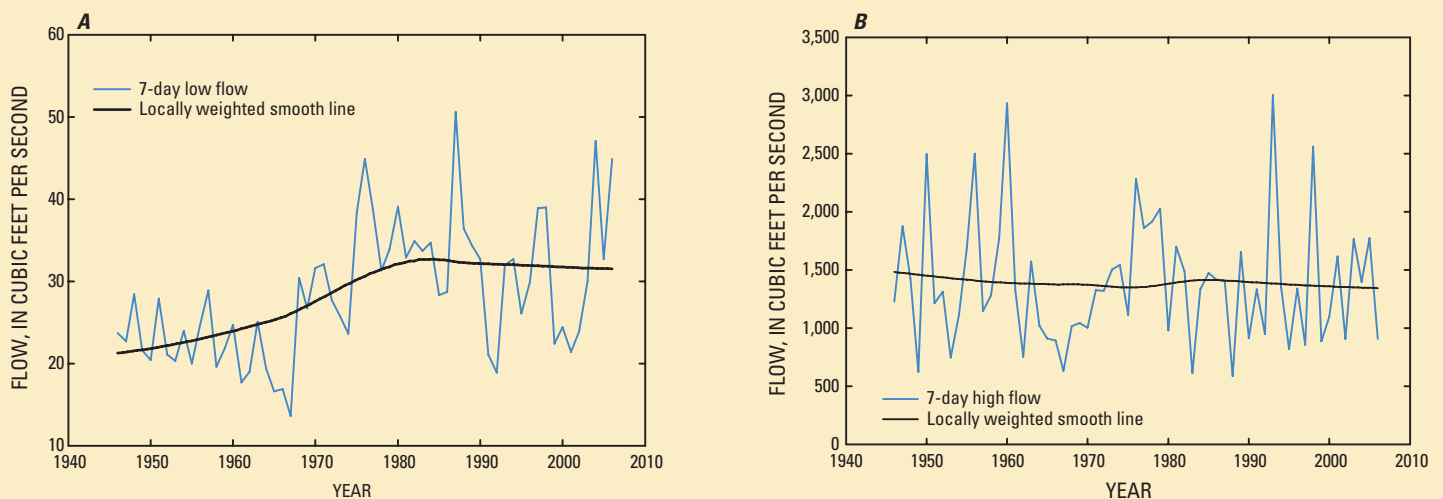
## Seven-Day Low and High Flows

A streamflow statistic that is commonly used by hydrologists to describe low and high flows is the 7-day mean low or high flow—the minimum or maximum average daily mean flow for any 7-consecutive-day period in a given year. These 7-day flows can be more representative of a stream’s flow conditions than instantaneous or daily flow values. Given that base flow represents from 60 to 70 percent of the annual streamflow in Monroe County streams, the upward trends for the 7-day low flows for the three rural streams (Oatka, Black, and Honeoye Creeks), which range from less than 1 ft<sup>3</sup>/s in Honeoye Creek to more than 10 ft<sup>3</sup>/s in Oatka Creek (figs. 10–12), are not surprising. A similar trend was reported for 27 streamflow sites throughout the Great Lakes Basin (within the United States) that are considered to be relatively free of human influences (Hodgkins and others, 2007). The plots in figures 10 and 11 show no discernible trends in the 7-day high flows on Oatka or Black Creeks, but the plot for Honeoye Creek (fig. 12) shows a slight increase in the 7-day high flows. The periodic spikes in the 7-day low flows and the deviations in the trend lines of the data from Honeoye Creek compared with those from the other two streams presumably are a result of regulation of the outflows from Hemlock and Canadice Lakes to the creek.

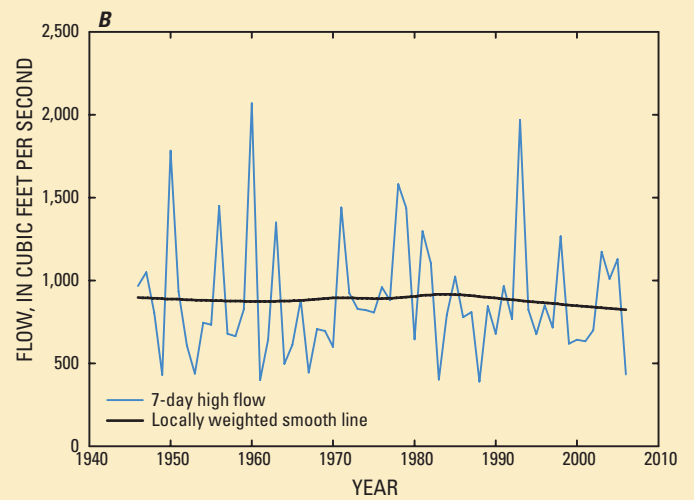
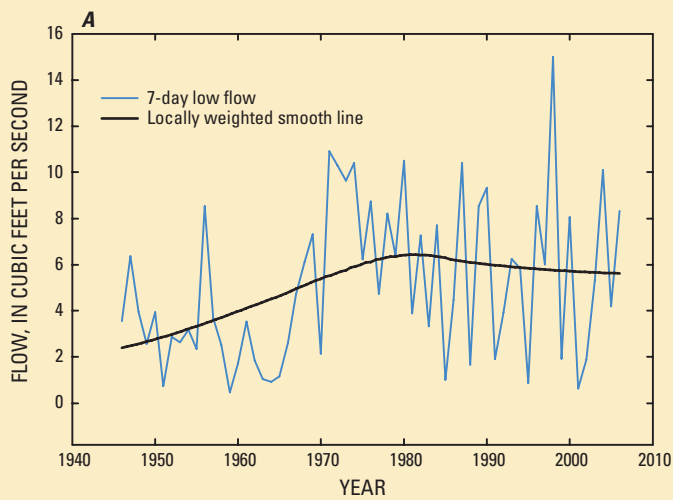
Unlike the 7-day low- and high-flow data shown for the two unregulated rural streams—Oatka and Black Creeks

(figs. 10–11)—the data for the urbanized Allen Creek Basin show a downward trend in 7-day low flows and an upward trend in 7-day high flows (fig. 13). Like the difference between the base-flow data for Allen Creek (fig. 9) and those for the rural streams (figs. 6–8), the differences between the 7-day low- and high-flow trends for Allen Creek and those for the rural streams can be attributed to the large amount of impervious area in the Allen Creek Basin. No discernible trends were detected in 7-day low and high flows for Irondequoit Creek.

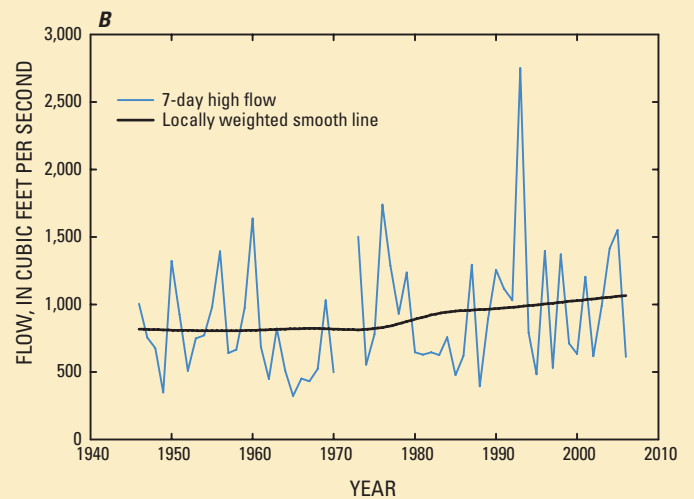
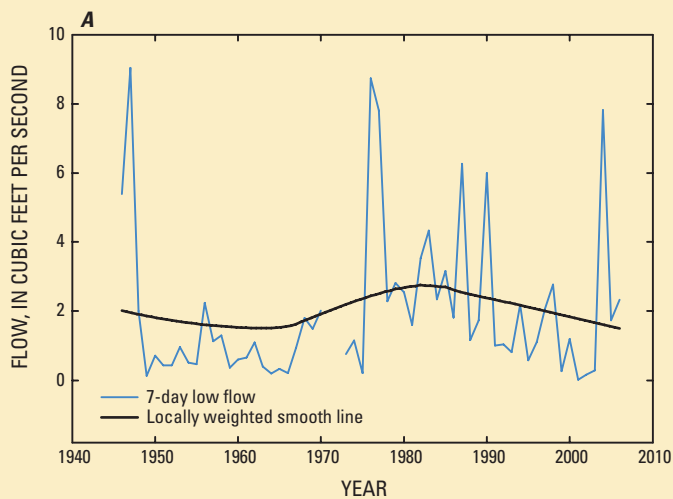
The trends identified here for the unregulated rural streams in Monroe County are consistent with results of a study of streamflow trends at 395 climate sensitive streamflow monitoring sites in the conterminous United States (Lins and Slack, 1999). That study identified (1) upward trends in annual minimum and median flows similar to those found for base flows and 7-day low flows in Monroe County, and (2) the absence of a predominant trend in high flows, similar to the absence of such a trend for the Monroe County 7-day high flow data. In addition, an analysis of streamflow data from 400 sites in the conterminous United States (McCabe and Wolock, 2002) concluded that the increase in low flows of streams in the eastern United States has not been gradual or continuous, but rather an abrupt step increase that occurred during the early 1970s. This step increase can be seen in the base flows for Oatka, Black, and Honeoye Creeks (figs. 6–8) and in the 7-day low flows for Oatka and Black Creeks (figs. 10–11).



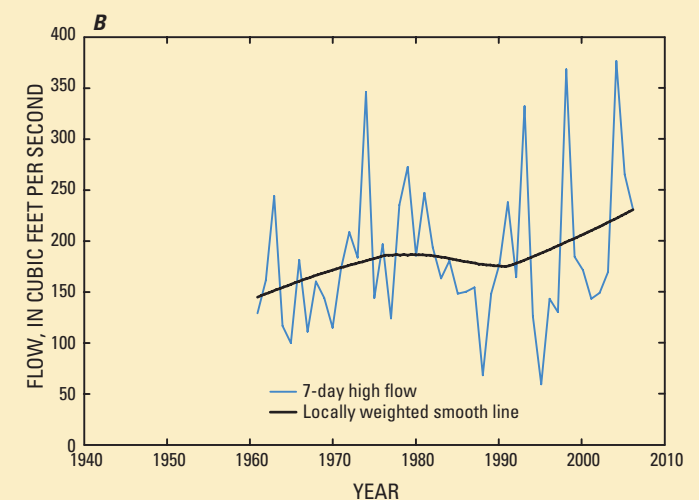
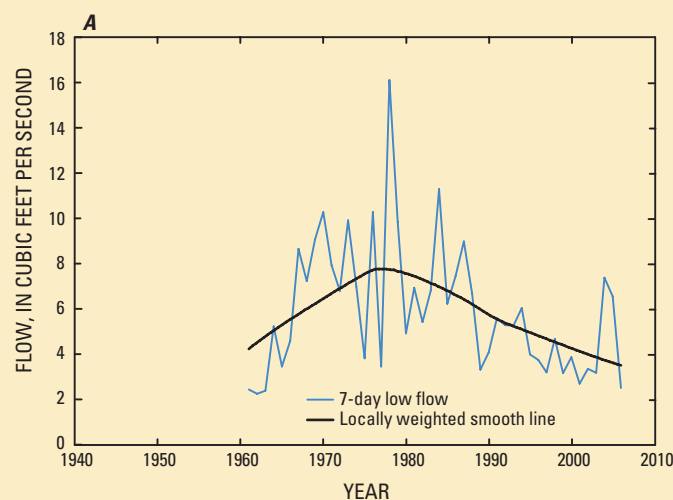
**Figure 10.** Seven-day (A) low and (B) high flows, Oatka Creek, 1946–2005.



**Figure 11.** Seven-day (A) low and (B) high flows, Black Creek, 1946–2005.



**Figure 12.** Seven-day (A) low and (B) high flows, Honeoye Creek, 1946–2005.

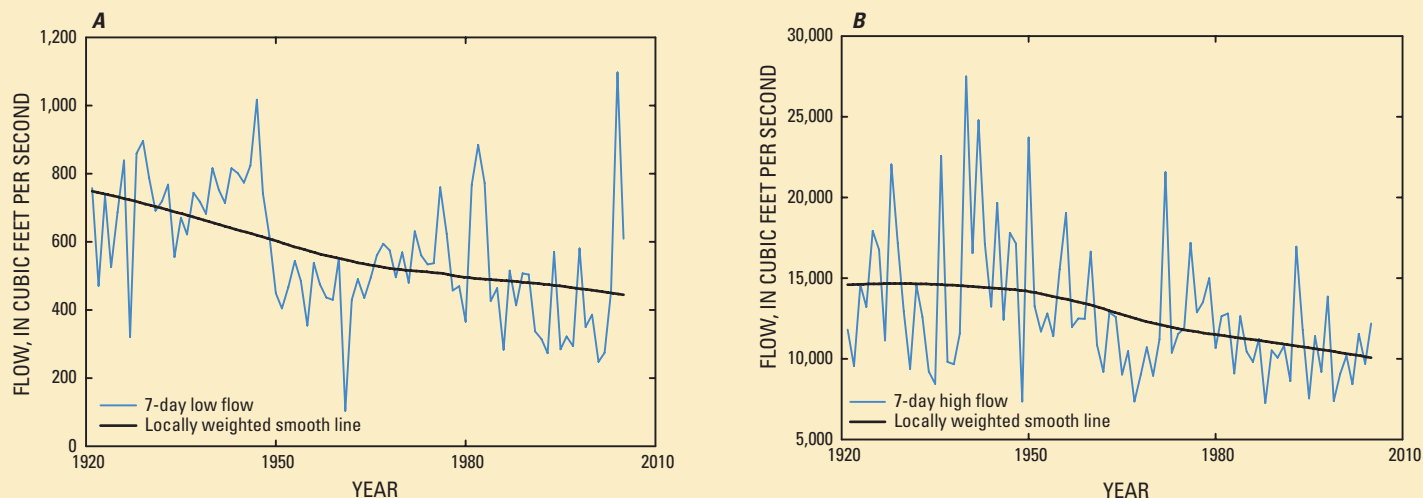


**Figure 13.** Seven-day (A) low and (B) high flows, Allen Creek, 1961–2005.

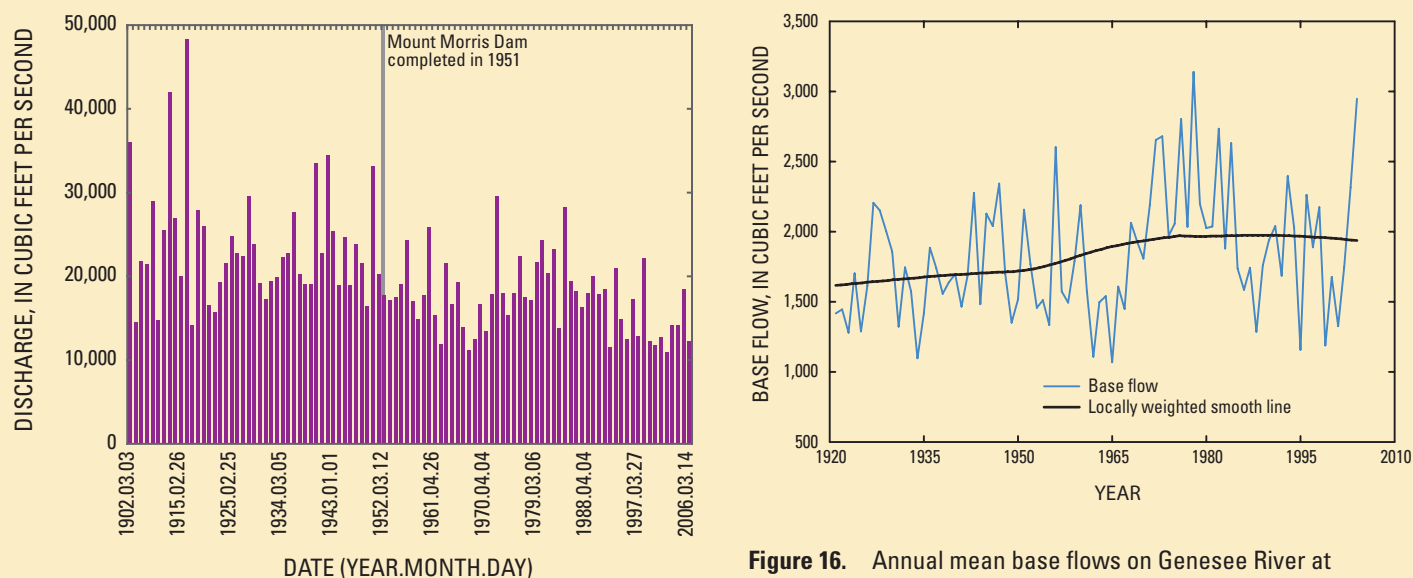
## Effects of Genesee River Regulation on Streamflow Characteristics

All previously discussed hydrologic characteristics of streams in Monroe County are applicable to the Genesee River, with one qualification: flow of the Genesee River has been regulated by the dam at Mount Morris since its completion in 1951 and, to a lesser degree, by Rushford Lake in Allegany County and Conesus Lake in Livingston County. In contrast to the minor effects of regulation of outflow from Hemlock

and Canadice Lakes on flows in Honeoye Creek, regulation of outflow from Mount Morris Lake has resulted in a marked decrease in both the 7-day low and high flows (fig. 14), as well as the number and magnitude of damaging floods in the Rochester area (fig. 15). The apparent increase in annual mean base flow in the Genesee River since 1920 (fig. 16) is consistent with that identified in other streams in Monroe County, but the upward trend downstream from Mount Morris Lake after 1951 presumably reflects sustained flows from dam releases rather than any effect of climate change.



**Figure 14.** Seven-day (A) low and (B) high flows, Genesee River at Rochester, N.Y., 1920–2005.



**Figure 15.** Peak flows on Genesee River at Rochester, N.Y., 1902–2007.

**Figure 16.** Annual mean base flows on Genesee River at Rochester, N.Y., 1920–2005.

## Summary

The long-term annual mean air-temperature record from the National Weather Service station at the Rochester, N.Y., airport indicates an apparent increase over the past 4 decades; however, this increase does not differ substantially from the historical range of temperatures during the last century. Annual precipitation totals are increasing, and this increase is reflected in the peak flows of streams in urbanized basins and in the base flows and 7-day low flows of two rural, unregulated streams—Oatka and Black Creeks—in Monroe County, N.Y. The magnitudes of recent peak flows, since about 1997, appear to be comparable to those of earlier peaks, but the frequency of peak

flows appears to be increasing, at least in the urbanized basins. Base flows and 7-day low flows are increasing as expected from the increasing amounts of precipitation, yet 7-day high flows show no discernible trends. In contrast, streamflow in the urbanized Allen Creek Basin, the hydrology of which is affected by its large amount of impervious area, shows downward trends in base flow and in 7-day low flows, and an upward trend in 7-day high flows. These differences between the urban and rural streams persist even when coincident periods of record are used in the analysis. Flow conditions in the Genesee River are unique because the regulation of outflow from Mount Morris Lake has decreased the number and magnitude of damaging floods downstream in the Rochester area and also has diminished the 7-day low and high flows in that reach.

By William F. Coon

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## Benefit of Long-Term Weather and Hydrologic Records

Climate ultimately affects every aspect of life on earth, including human health and well-being. Recent changes in climate have increased the frequency and intensity of floods, droughts, and wildfires, and also have resulted in increased crop failures, outbreaks of disease, and insect damage to crops and structures. The National Weather Service has maintained a long-term weather station at the Greater Rochester International Airport, while the U.S. Geological Survey (USGS), in cooperation with other Federal and State agencies and the Monroe County Department of Health, has operated a network of streamflow-monitoring sites in the County. The data from these sites can be analyzed to determine if and how the local weather is changing and how climate change might affect the local water resources.

Analyses of the long-term precipitation and streamflow records indicate that Monroe County's average annual precipitation is increasing, and that the amount of water flowing in local streams has increased accordingly. Despite this trend, drought remains an annual possibility. The observed changes in the amount, timing, and distribution of rain, snow, and runoff pose a challenge to the management of water resources, infrastructure, and services. Whether the identified seasonal and annual trends in streamflow will continue into the future or are merely short-term expressions of long-term natural cycles that will eventually reverse direction is unknown, but continued meteorological and streamflow monitoring is vital to the forecasting of future climatic conditions and their implications, and to the preparation of strategies to minimize the attendant risks to human life and damage to property and infrastructure.

